Cryocooler Considerations for a Far IR Surveyor

Far IR Surveyor Workshop

Mike DiPirro, NASA/GSFC

4-June-2015

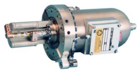
Cryocooler Basics

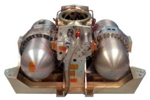
- Cryocoolers vs. stored cryogens
  - Long life per mass

Recent Long-Life Space Cryocooler Flight Operating Experience as of Oct 2013

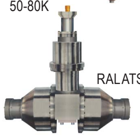
Cooler / Mission	Hours/Unit	Comments
Air Liquide Turbo Brayton (ISS MELFI 190K)	63,000	Turn on 7/06, Ongoing, No degradation
Ball Aerospace Stirling		
HIRDLS (60K 1-stage Stirling)	80,000	Turn on 8/04, Ongoing, No degradation
TIRS cooler (35K two-stage Stirling)	7,000	Turn on 3/6/13, Ongoing, No degradation
Creare Turbo Brayton (77K NICMOS)	57,000	3/02 thru 10/09, Off, Coupling to Load failed
Fujitsu Stirling (ASTER 80K TIR system)	119,400	Turn on 3/00, Ongoing, No degradation
JPL Sorption (PLANCK 18K JT (Prime & Bkup))	27,500	FM1 (8/10-10/13 EOM); FM2 failed at 10,500 h
Mitsubishi Stirling (ASTER 77K SWIR system)	115,200	Turn on 3/00, Ongoing, Load off at 71,000 h
NGAS (TRW) Coolers		
CX (150K Mini PT (2 units))	139,000	Turn on 2/98, Ongoing, No degradation
HTSSE-2 (80K mini Stirling)	24,000	3/99 thru 3/02, Mission End, No degrad.
MTI (60K 6020 10cc PT)	119,000	Turn on 3/00, Ongoing, No degradation
Hyperion (110K Mini PT)	111,000	Turn on 12/00, Ongoing, No degradation
SABER (75K Mini PT)	107,000	Turn on 1/02, Ongoing, No degradation
AIRS (55K 10cc PT (2 units))	99,000	Turn on 6/02, Ongoing, No degradation
TES (60K 10cc PT (2 units))	80,000	Turn on 8/04, Ongoing, No degradation
JAMI (65K HEC PT (2 units))	72,000	Turn on 4/05, Ongoing, No degradation
GOSAT/IBUKI (60K HEC PT)	40,700	Turn on 2/09, Ongoing, No degradation
STSS (Mini PT (4 units))	30,200	Turn on 4/10, Ongoing, No degradation
Oxford/BAe/MMS/Astrium Stirling		
ISAMS (80 K Oxford)	15,800	10/91 thru 7/92, Instrument failed
HTSSE-2 (80K BAe)	24,000	3/99 thru 3/02, Mission End, No degrad.
MOPITT (50-80K BAe (2 units))	114,000	Turn on 3/00, lost one disp. at 10,300 h
ODIN (50-80K Astrium (1 unit))	110,000	Turn on 3/01, Ongoing, No degradation
AATSR on ERS-1 (50-80K Astrium (2 units))	88,200	3/02 to 4/12, No Degrad, Satellite failed
MIPAS on ERS-1 (50-80K Astrium (2 units))	88,200	3/02 to 4/12, No Degrad, Satellite failed
INTEGRAL (50-80K Astrium (4 units))	96,100	Turn on 10/02, Ongoing, No degradation
Helios 2A (50-80K Astrium (2 units))	74,000	Turn on 4/05, Ongoing, No degradation
Helios 2B (50-80K Astrium (2 units))	30,200	Turn on 4/10, Ongoing, No degradation
Raytheon ISSC Stirling (STSS (2 units))	30,200	Turn on 4/10, Ongoing, No degradation
Rutherford Appleton Lab (RAL)		
ATSR 1 on ERS-1 (80K Integral Stirling)	75,300	7/91 thru 3/00, Satellite failed
ATSR 2 on ERS-2 (80K Integral Stirling)	112,000	4/95 thru 2/08, Instrument failed
Planck (4K JT)	38,500	5/09 thru 10/13, Mission End, No Degrad.
Sumitomo Stirling Coolers		
Suzaku (100K 1-stg)	59,300	7/05 thru 4/12, Mission End, No degradation
Akari (20K 2-stg (2 units))	39,000	2/06 to 11/11 EOM, 1 Degr., 2nd failed at 13 kh
Kaguya GRS (70K 1-stg)	14,600	10/07- 6/09, Mission End, No degradation
JEM/SMILES on ISS (4.5K JT)	4,500	Turn on 10/09, Could not restart at 4,500 h
Sunpower Stirling (75K RHESSI)	102,000	Turn on 2/02, Ongoing, Modest degradation


Creare NICMOS


NGAS (TRW) Mini PT


NGAS (TRW) AIRS PT


Astrium (BAe) 50-80K


RALATSR


Sunpower

Ross 10/05/13

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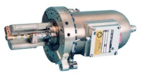
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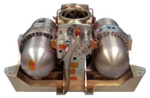
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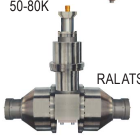

RAL ATSR

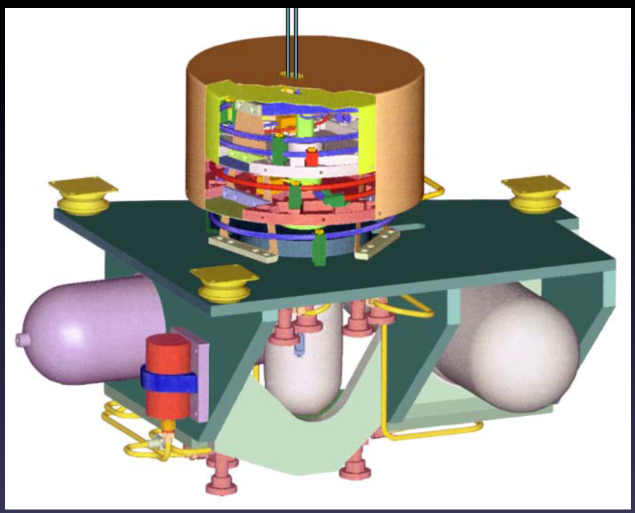
Sunpower

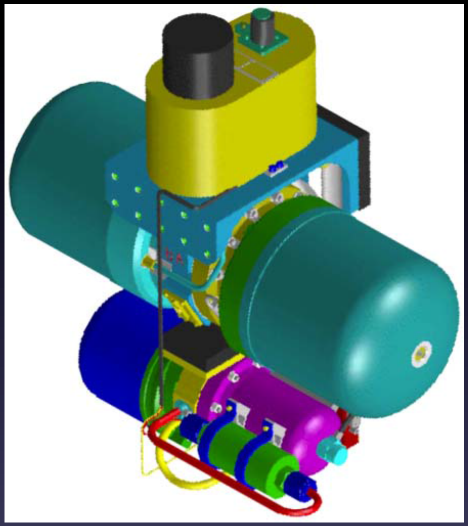

Ross 10/05/13

Listing of Space Cryocoolers

- From Ron Ross
- Minimal number of sub 15 K coolers
- Mechanical reliability is very high

ACTDP Developed Cryocoolers





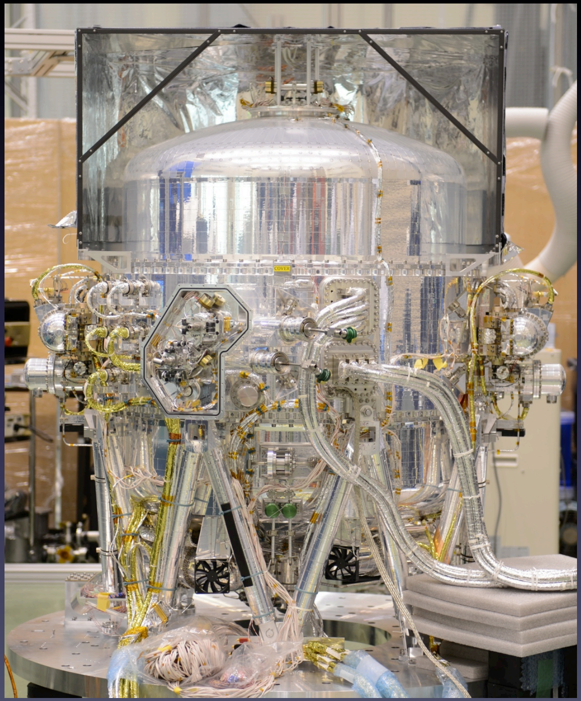
Ball
JT cooled by
2 stage Stirling

Northrop
JT cooled by
2 Stage Pulse Tube

Lockheed
4 stage Pulse Tube

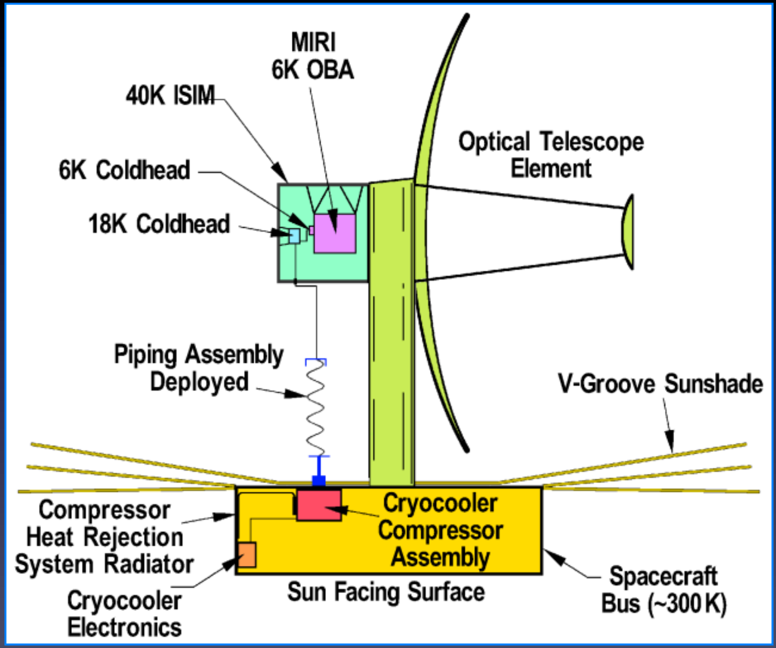
Near Term Flight Cryocoolers

Astro-H SXS



5 cryocoolers + helium dewar

JWST/MIRI



Cryocooler system spans room temperature to 40 K external environment

Optimization Parameters

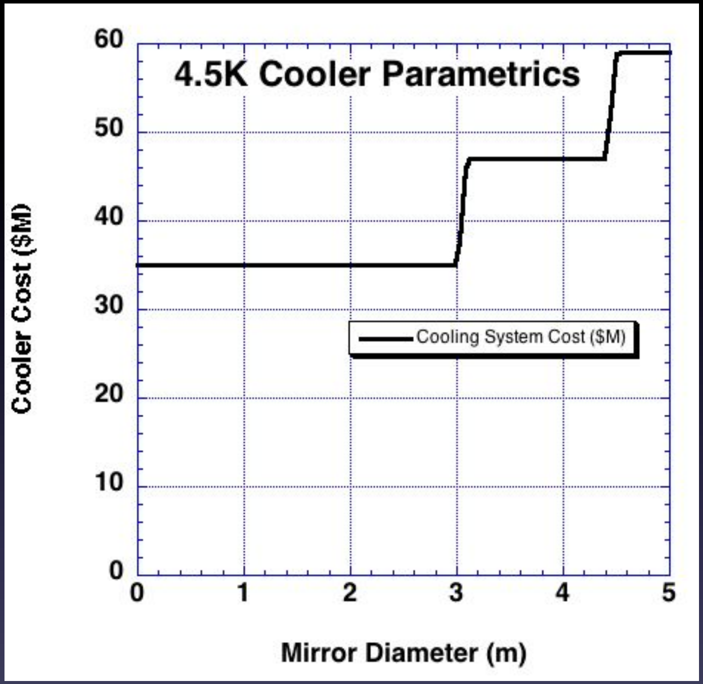
- TRL
- Cost
- Input Power
- Sizing and Operating Temperature
- Reliability
- Compatibility

TRL

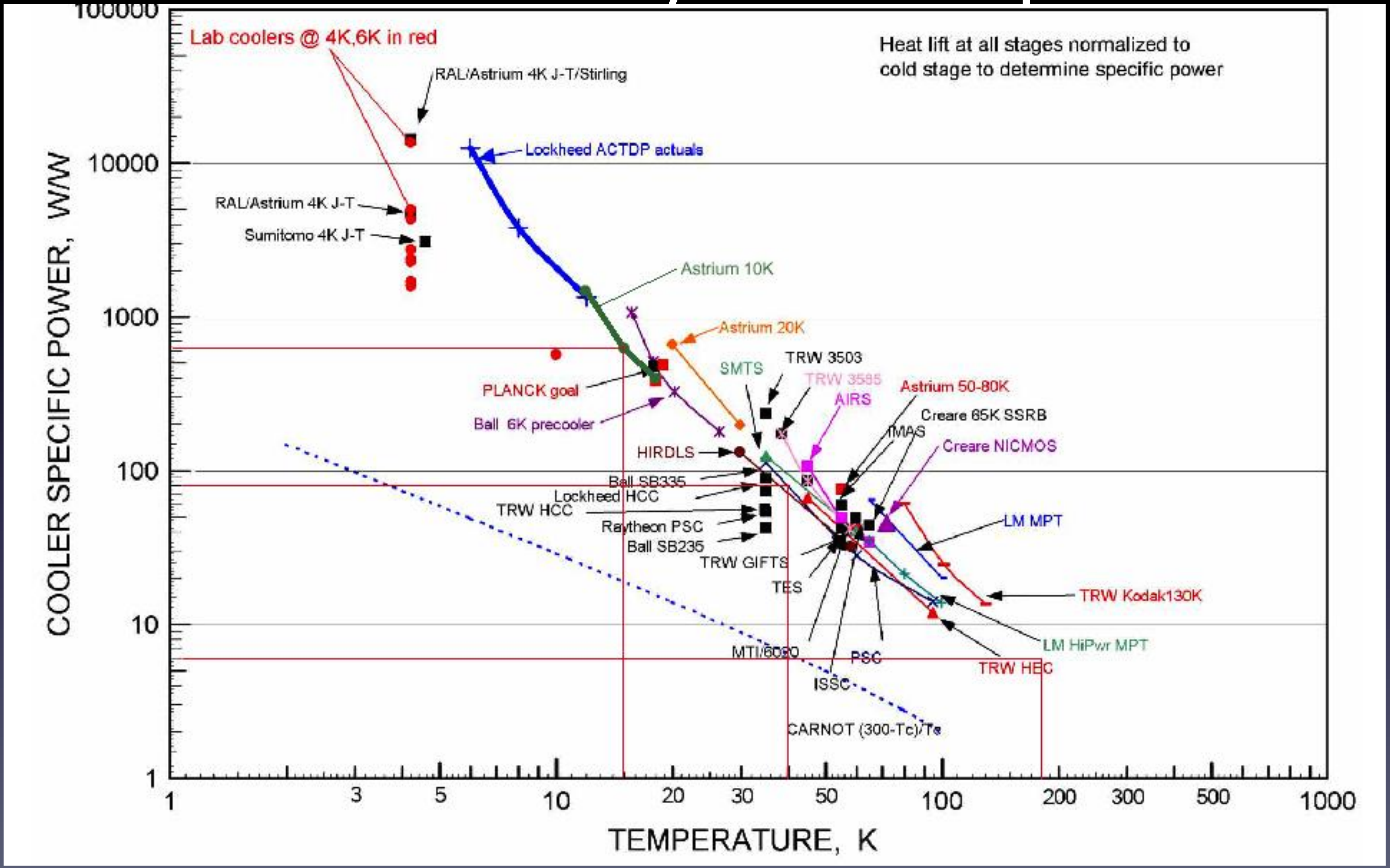
- What is needed for flight? (TRL 7)
- What is needed for Phase A? (TRL 4-5)
- For Phase C/D ? (TRL 6)
- What T< 6K cooler exists for TRL 4+?
  - Ball
  - NGAS
  - Lockheed
  - Sumitomo
  - Others
    - Planck cooler
- Raising TRL level is difficult because mid-TRL development money is scarce

Cost

- Development cost of cryocooler to TRL 6 takes time and several $M
  - For higher heat loads using multiple existing design coolers may be more cost effective
- Verification can be very expensive for a large system
  - Component level testing only
  - Subscale testing
  - Local cooling for a large distributed system
  - Better T/V chamber blackness can allow smaller chamber
    - Honeycomb panels for walls



Cooler Efficiency vs. Temperature



Input Power

- Dean Johnson's Graph
  - To produce ~4 K need ~10^4 W/W input power
  - A few % of Carnot, which gets worse as operating temperature is lowered
- Current 4 K Cryocoolers are all in the range of 400-500 W input power produces 40-50 mW of cooling at 4.5 K

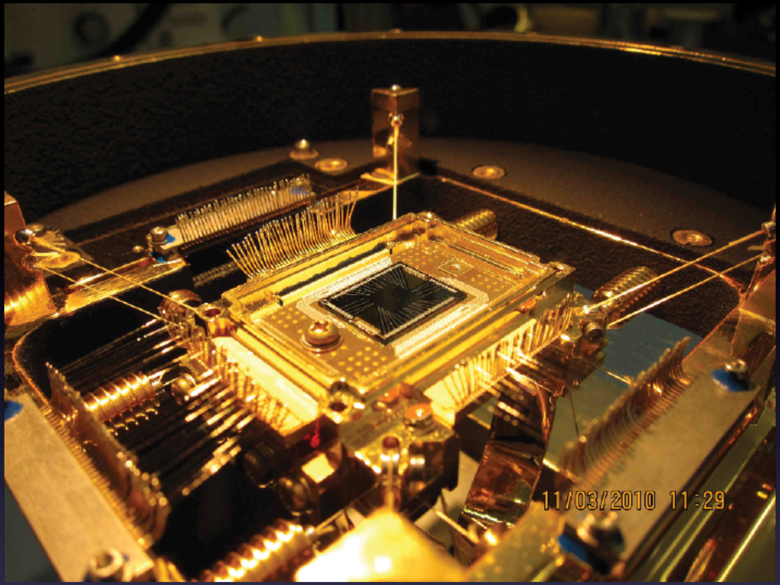
Sizing and Temperature

- JT technology means that there is a peak cooling power vs. temperature
  - Typical temperatures are 4-6 K
- Stirling or Pulse Tube coolers typically do no cool below about 15 K
- Smaller is more difficult than larger
- Cooling power required goes as cold mass
  - Structural supports are typically the largest source of parasitic heat
  - Cold mass roughly proportional to telescope area plus an overhead
  - Spitzer had 138 kg of supported mass at 5.5 K with a heat leak of about 6 mW

Reliability

- Mechanical System
  - Has been shown to have high reliability
    - $10^4 – 10^5$ hours MTBF for compressors
  - Contamination and very slow wear remain life-limiting
- Electronics
  - Usually fully redundant
- Redundancy in general
  - JWST uses fully redundant electronics but no mechanical system redundancy
  - Astro-H has fully redundant electronics and some mechanical systems - BUT
- Heat Switches
  - For redundant mechanical system heat switches may be required

Compatibility



- Vibration
  - Image disturbance
  - Microphonics
  - Direct heating of low temperature detectors
- EMI
- Heat sink for sub-kelvin coolers

Other

- Ground Testing
  - Cryocoolers need help cooling down
    - SXS instrument predicted to take 52 days to cool down from room T
    - But cooling lines attached to hardware prevent accurate thermal evaluation (e.g., Spitzer CTA)
  - Elimination of dewar saves a lot of mass, volume, and aperture cover, servicing, but now requires a thermal/ vacuum chamber as a substitute

Summary

- Cryocooler technology for cooling to 4-5 K exists
  - Complex integrations have been implemented
- Cryogenic systems, in general, require careful design considerations from beginning
  - Take advantage of well know techniques for thermal staging and use of materials
  - Use lessons learned from Spitzer, Planck, Hershel, JWST, ASTRO-H, etc.